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Maintaining perspective of ongoing environmental change in the Mekong floodplains

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The Mekong River remained hydrologically unregulated until recent decades and still harbors immense natural resources that are the basis of rural livelihoods. Research on how dams and climate change could alter the river has heightened in recent years, and while this research has led to important scientific concepts and increased discussion of sustainable development, it has done little to prevent the rapid environmental change in the Mekong floodplains of Cambodia and Vietnam. Meanwhile, localized drivers of floodplain change (including overfishing, deforestation, and water infrastructure development) are impacting the environment in faster and more direct ways, potentially exacerbating the negative effects of regional factors such as hydropower and climate change. Sustainable development of the basin must include comprehensive science and implementable policy programs that integrate across regional and local scales and focus on clearly defined societal and policy goals, collection of critical data, capacity building of in-region scientific and policy institutions, effective law enforcement, and adaptable implementation strategies.

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Introduction

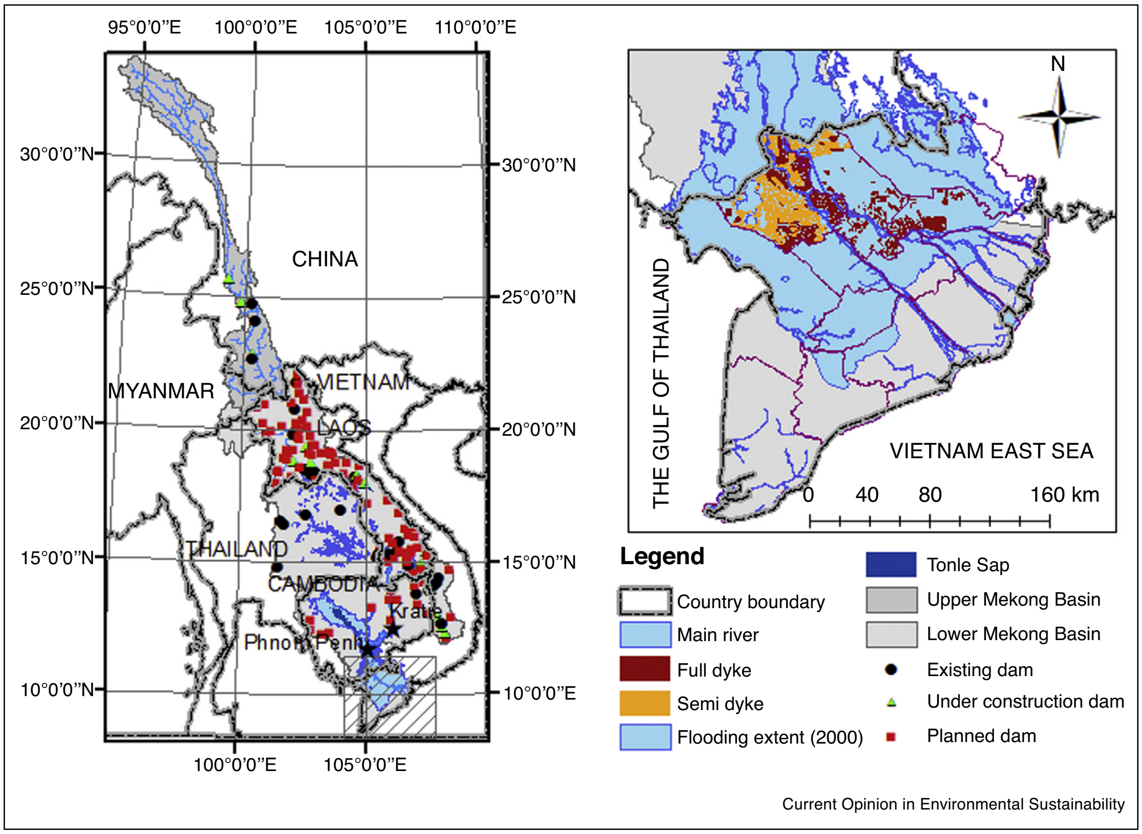
The Mekong floodplains are home to one of the largest fisheries on the planet and provide the dominant source of animal protein to millions of people in Cambodia and Vietnam. Covering approximately 70 000 km^2, these floodplains include the largest contiguous wetland in Southeast Asia (the Tonle Sap) and paddies where more than 50% of Vietnam's rice is cultivated [1]. War and political turmoil in the 1970–1980s prevented much development in the region, but more recent decades have seen very fast economic growth fueled by wider integration to the global economy. This has sparked greater exploitation of basin-wide natural resources for local consumption and export, manufacturing, and energy generation. In particular, hydropower generation has been growing exponentially in the Mekong Basin [2], and it is expected to continue in decades to come at a much faster rate than in most of the world [3,4]. Such trends have alarmed conservationists and scientists, who perceive hydropower in the Mekong as an existential threat to one of the last remaining gems for river biodiversity [5] and the livelihoods of millions of people among the rural poor who highly depend on the river and natural resources [6]. Yet, major research and monitoring gaps have prevented a good understanding of past and ongoing impacts of dams on freshwater ecosystems, fisheries, and livelihoods. Equally important, and the main argument of this article, is that emphasis on dams alone has distracted the discussion – and potential policy implications – from under-appreciated local threats that have already paid a significant toll on the Mekong floodplain environment resulting in diminished ecosystem services including water regulation, food production, and wildlife habitat.

Here, we illustrate recent environmental changes in the Mekong floodplains, focusing on water resources, floodplain vegetation, and fish. We argue that efforts by the international scientific community to advance knowledge on sustainability in the Mekong has weighed the attention on hydropower dams alone, while a number of local drivers are rapidly transforming the floodplains and could fuel further ecosystem deterioration. Finally, we highlight strategies to improve sustainability of the Mekong floodplains.

Background on Mekong floodplains

The Mekong is a river basin covering approximately 748 000 km^2 in China, Myanmar, Thailand, Lao PDR, Cambodia, and Vietnam (Figure 1). The river runs for approximately 4800 km and a total elevation drop of over

Figure 1



Mekong river basin map, highlighting hydropower dam locations and floodplains (left frame) and flood prevention projects in the Mekong Delta in Vietnam (right frame).

5000 m. The floodplain proper only begins once the river reaches Central Cambodia, nearly 600 km before the river discharges into the Sea. The floodplain is generally divided in three regions: the central floodplains, which span along the Mekong in Cambodia from the town of Kratie to the border with Vietnam, the Tonle Sap floodplain, which covers an area of approximately 15 000 km^2 along the river and around the lake with the same name, and which are directly connected to the Mekong at Cambodia's capital, Phnom Penh. Farthest downstream, the heavily farmed and populated region is referred as the Vietnam Delta. River discharge and floodplain inundation are strongly seasonal as 80–90% of the rainfall falls in the months of May to October [7].

Facts on impacts of hydropower dams on the Mekong floodplains

A number of extensive reviews on impacts of hydropower dams on the Mekong hydrology have been recently published [8–11]. We refer the reader to these recent publications for detail analyses of effects of Mekong dams on river flows and sediments, as well as their interplay with other regional drivers such as climate change and land use conversion.

Most of the documented dam-induced changes along the Mekong and its floodplains relate to water levels and discharge. Increases in mean dry season flows and water level fluctuations have been evident in Central Cambodia down to the Tonle Sap River since the early 1990s, when the first large dam was built in the upper Mekong in China [2,12,13]. These observed alterations in the hydrological records are in agreement with patterns of change demonstrated with water resources numerical models [12,14–16], providing good evidence that dams in the upper basin and tributaries have indeed been responsible for hydrological changes in the lower Mekong.

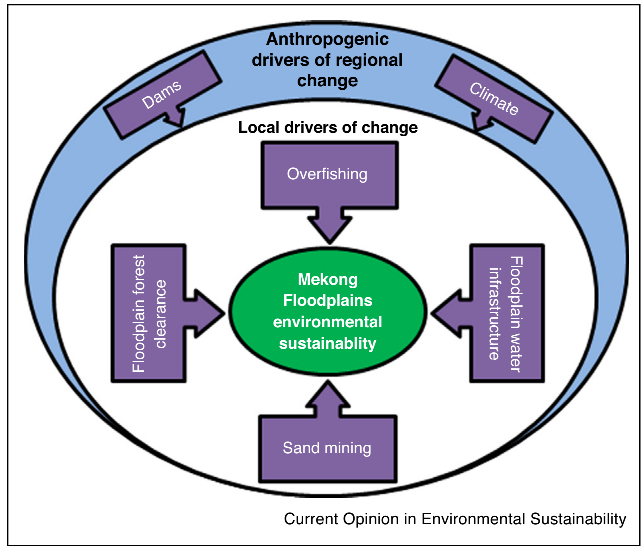
Several modeling projections have argued that dams could trap a significant amount of sediments and nutrients feeding the floodplains [17–19]. Indeed, evidence from monitoring stations supports that suspended sediment load in the lower Mekong has declined since 2009 [11]. Several other studies have suggested an eventual impact of dams on fish migration connectivity [20], aquatic primary production [17], habitat suitability [21], and nutrition value [22]. While there is evidence of impacts of dams on fish populations in the lower Mekong tributaries [23], there is no undisputable scientific evidence

directly supporting such ecological impacts – beyond hydrological alterations – have begun in the floodplains.

Current drivers of drastic floodplain environmental changes

Much attention from international scientific and environmental communities have focused on hydropower and climate change, drivers of change that are dictated by processes and decisions at the global to multi-country scales. Meanwhile, more local and immediate threats driven by decisions and actions at the subnational to household scale have been causing serious – and arguably irreversible – damage to the floodplain environment since the 2000s. Despite the difference in the scale where these drivers originate, they eventually have an effect on the floodplain environment, and the interactions between them could actually exacerbate impacts more than if regional or local drivers were to occur in isolation. A clear example of this multiscale interconnection described elsewhere in detail is sand mining [11,24], a practice now banned in Cambodia and the Vietnam Mekong Delta. The mining and transport of river sand allow rapid development to reclaim land and elevate roads and levees above flood level in the low land areas. Without effective monitoring and enforcement, sand mining will continue to have a great impact in the Mekong's river bed geomorphology, sediment load, and wetland areas, which in combination with sediment trapping in reservoirs and other drivers could further exacerbate the issue of sediment limitation in the floodplains [24]. While we attempt to represent conceptually the interactions between dams and other drivers of floodplain environmental change in the Mekong (Figure 2), this is a rather simplistic model that does not illustrate the non-linearity of connections among hierarchies and exclude equally important local drivers such as wastewater and urbanization.

Figure 2



Conceptual integration of major local and regional drivers of change in the Mekong floodplains. Note that there are several other drivers that are not included in this diagram or discussed in this opinion paper due to space limitation.

Water infrastructure development

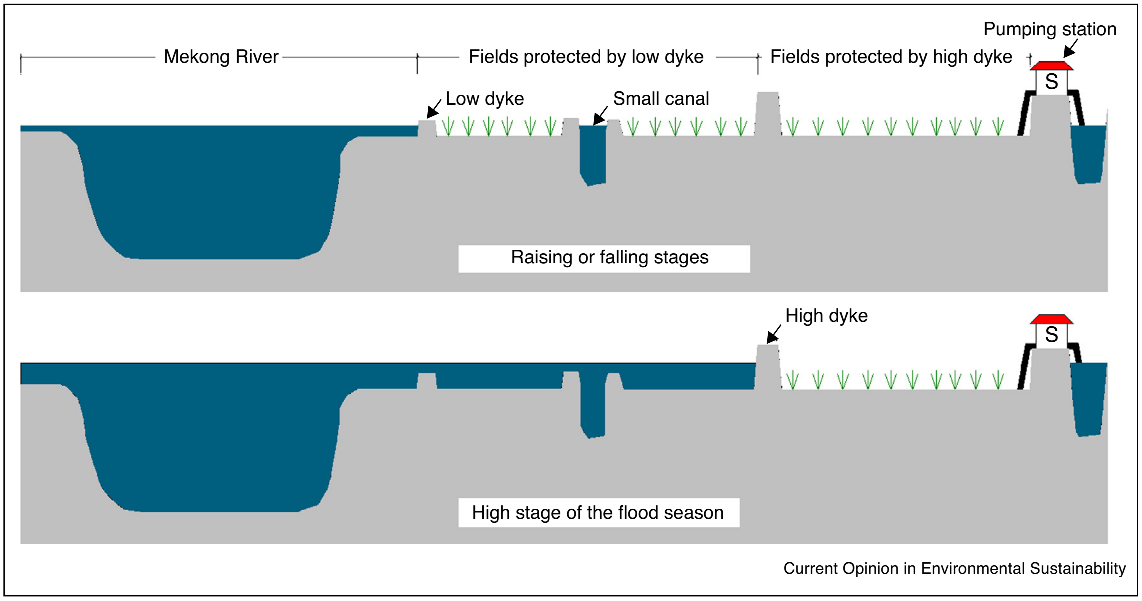
Irrigation canals, drainage channels and flood prevention dykes are now widespread throughout the floodplains [25,26]. There has been a significant increase in agricultural productivity in areas where early flood-protection low dykes have been converted to high dykes, thus allowing three rice crops per year (Figure 3). However, this conversion has led to drastic and fast alterations to water and sediment fluxes into the agricultural dominated regions of the floodplains. Between 2000 and 2013, for instance, the construction of dykes in the Vietnam Mekong Delta, reduced the flooding area in the Long Xuyen Quadrangle by 36%, which has subsequently exacerbated flooding in unprotected regions downstream [26]. Further development of the dyke systems would reduce water transfer capacity through the floodplains, resulting in an increase of water levels locally [27]. In terms of sedimentation, satellite data analysis showed that low dykes have little impact on sedimentation in fields in early August, while high dykes have prevented nutrients-rich sediments from going into agricultural fields [28]. Besides the evident physical alterations, the widespread and fast construction of water infrastructure happening in Vietnam has brought several management challenges, including lack of coordination, conflicting interests, and unwanted impacts among planning departments and provinces [29].

Overfishing

The core of the highly productive and diverse Mekong fisheries is in the Tonle Sap (Figure 4), a complex system of rivers, a lake, and a floodplain covering 11% of Cambodia. For over a century, large-scale fishing occurred in concessions (a.k.a., fishing lots) covering most of the Tonle Sap floodplain. The lot system prevented access to prime fishing grounds by the rural poor, but centralized control of fishing among a relatively small number of individuals. These private concessions were abolished in 2012, allowing nearly unfettered fishing and few viable mechanisms to control fishing effort [30].

The *Indiscriminate Fishery* the Tonle Sap portrays [31,32] employs a variety of fishing gears across seasons, habitats, fish species, and sizes [32,33]. The result is that slower growing, larger-bodied, and higher tropic riverine species are declining in the catch, while faster growing, smaller-bodied, and lower trophic fishes are increasing [34]. The declining catch of medium-bodied and large-bodied species as well as the reduction in mean fish weight [34] are indeed consistent with fishers' perception [35,36]. Theory

Figure 3



River and floodplain cross-section highlighting the effect of flood prevention infrastructure in the floodplains.
Adapted from [1].

suggests dominance of smaller, more productive fishes is likely to increase fish productivity overall, but at the cost of reduced biodiversity and lower reliance to environmental perturbation [32]. In practice, it is clear that intensive indiscriminate fishing has led to dramatic changes in the Tonle Sap food web; however, the lack of systematic monitoring data means the ecological impacts of biodiversity reduction through fishing and the sustainable level of harvest for the fishery over the long-term remain unknown.

Deforestation

Burning of agricultural lands has been a historical practice in the Mekong, but recent large-scale clearance of lowland forests has transformed the floodplain landscape at an unprecedented rate and magnitude. There is evidence of sporadic fires throughout the Tonle Sap floodplain (Figure 4), in particular near agricultural areas and permanent water bodies [37]. However, the non-agricultural region of the floodplain remains inundated for 5–9 months annually [38], providing moisture for the remaining of the

Figure 4

Left: Demonstration of intensive fishing activity in the Tonle Sap River (Photo credit: Zeb Hogan). Right: Local fires are a common occurrence in the floodplain, but the extent of recent fires is unprecedented, while chances of natural vegetation recovery is highly influenced by inundation patterns and agricultural activity (Photo credit: M.E. Arias).

year when conditions are much drier. The El Niño phase in 2016 brought one of the driest years in the hydrological record in the floodplains, which facilitated widespread fires in some of the wettest, most biologically diverse, and protected areas. Unpublished estimates indicate that approximately 8000 ha burned in the Prek Toal Protected Area alone [39]. On the basis of global datasets of deforestation [40], recent deforestation rates in areas surrounding the Tonle Sap watershed were estimated at 0.9–1.7% annually, one of the highest on the planet. The regionally important Tonle Sap fishery is based to a large degree on floodplain forests as habitats and food resources derived from organic matter from the surrounding vegetation [41]. The loss of flooded forests and wetlands also jeopardizes numerous bird species [21,42] that use these critical habitats, as well as ecosystem services to local people including water purification, raw materials, and food.

The way forward

Sustainable development of the lower Mekong Basin through integrated water resources management has been a shared goal of Cambodia, Lao PDR, Thailand, and Vietnam since the signing of the Mekong Agreement in 1995, at which time the Mekong River Commission (MRC) was also established as the mechanism for implementation [43]. The MRC and its member countries have had notable successes at advancing sustainable water resources development on both the scientific and policy fronts – for example, long-term hydrologic monitoring and flood forecasting – however, a number of critical steps in science, policy, and implementation still need to occur to achieve a sustainable Mekong.

Expanded long-term and short-term data sets quantifying biological resource dynamics and their environmental drivers are desperately needed to assess changes and develop concrete management actions to protect floodplain ecosystems. Currently, the longest continuous record of a biologic resource comes from the seasonal Tonle Sap River stationary trawl (dai) fishery monitoring program initiated in 1994 [44,45]. Advances in sensor technology, remote sensing, data capture, and management now offer the potential for distributed, continuous monitoring of populations and environmental conditions that can be used for real-time forecasting and management of resources. For example, remotely sensed bioacoustics monitoring of fishes migrating into and out of the Tonle Sap River could provide continuous estimates of fishing mortality, which can then be used to manage fisheries dynamically to achieve survival targets and, over multiple generations, provide the population-level and environmental information needed to achieve sustainable yields.

Concurrent with new technologies, local scientific capacities must also be developed to manage the data infrastructure and utilize the information being acquired. Specifically, there is acute need for advanced training in data science, computing, environmental science (e.g. fisheries, hydrology, forestry), science communication, and natural resource management and economics. Highly motivated students are increasingly being trained in competitive educational programs globally, but ultimately the educational capacity within these fields must be established locally for long-term success.

Lastly, even the best science and technology will do little to improve sustainability unless subnational, national and regional policy-makers set clear and measurable societal goals for natural resources and economic development and promote legal and institutional frameworks for their management. Policies already exist to address several, if not all, of the individual threats discussed in this article; ensuring that these policies are not conflicting with each other and realizing full implementation and effective enforcement is a necessary first step. For example, the policy change from private commercial concessions to community fisheries co-management was a promising pathway for more sustainable floodplain fisheries in Cambodia [30], but such a policy suffers from governance challenges, including unclear stakeholders' roles and responsibilities, poor coordination among responsible agencies, limited decentralization of roles and responsibilities, corruption, and strong livelihoods dependency of local communities on fisheries [46]. As a result, conflicts over access rights to natural resources, clearance of flooded forest amid dry season rice farming expansion, fish exploitation and water use are intensifying. To successfully implement such policy, a clear and coherent legal framework is needed to enhance effective law enforcement, improve planning, coordination and cooperation among stakeholders at all levels across multiple agencies and sectors, and diversify local communities' alternative livelihoods. As new information and tools become available, so do opportunities for partnership between multiple sectors to promote shared benefits and minimize conflicts. A sustainable future for the Mekong is only achievable with well-defined policy objectives, critical new data, highly trained science professionals, and robust policy implementation institutions.

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